Home-to-Home Communications for Smart Community with Internet of Things

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Abstract— **Internet of Things (IoT) has been prevailing to offer advanced connectivity of devices, systems, and services. As connected IoT devices have enhanced smart home, connected smart homes are expected to grow into smart community. However, several previous studies about smart community require a remote central server and do not consider local collaboration based on local direct communication networks. This paper proposes home-to-home (H2H) communication based on wireless communication between homes in a local community. Several types of local collaborations are described. Two plausible H2H communication architectures are presented such as centralized and distributed. Two architectures are evaluated using two metrics: traffic volume and communication reliability. Clustering is also adopted to reduce traffic volume. The evaluation results show that the centralized architecture is superior in traffic volume and it is more adequate for all-to-all type of local collaboration such as information sharing; that the distributed architecture is superior in communication reliability and it is more adequate for one-to-all type of local collaboration such as safety and security. Clustering greatly reduces traffic volumes. Therefore, the proposed H2H communications will provide more efficient communication and more reliable services under the circumstances of IoT-enabled smart homes.**

Keywords—Internet of Things, Wireless Sensor Network, Smart Community, Smart Home, Local Collaboration

I. Introduction

For one or two decades, home networks have steadily progressed and have been necessities in a smart home. At an early development stage, wired communication technologies were used to realize home networks; recently, wireless communication technologies have been used to connect home devices [1], [2]. These home devices can be monitored and controlled remotely through the Internet. This kind of home environment is considered as a part of the Internet of Things (IoT) which is an emerging concept referring to networked everyday objects and a novel paradigm that is rapidly gaining ground in the scenario of modern wireless communications [3]. A special dedicated device, called a home gateway (HG), connects IoT devices to a public Internet [4], [5].

A local community is a group of homes in one particular area. As connected IoT devices have improved smart home, connected smart homes can evolve into smart community. In a smart community, smart homes play a role of a multifunction sensor with individual purposes and continuously monitor the community environment; then, actions based on the monitored environmental data are taken to improve community safety, security, healthcare quality, and emergency response abilities [6], [7]. However, in the above studies, the proposed smart communities require a central server to provide services. They do not consider local collaboration between homes and local decisions. Home-to-home (H2H) communications are necessary for local collaboration and local decision.

This paper proposes H2H communication architectures without a central server among neighboring homes to share various data from IoT devices in individual homes and to provide smart community services rather than smart home services. The proposed H2H communication enables local collaboration between homes and help make local decisions based on various IoT devices in a community. Two plausible H2H communication architectures are presented: centralized and distributed. In addition, hierarchical clustering is adopted to reduce traffic volume and to increase network scalability [8].

The rest of the paper is organized as follows. Section II describes smart community services and types of local collaboration. Section III describes the architectures of H2H communication for local collaboration in a smart community. Section IV shows the evaluation results of the proposed architecture. Finally, section V concludes the paper.

II. Use Cases of Smart Community Services Based on H2H Communication

A. Examples of Smart Community Services

If individual homes share their data from IoT devices with other homes, various smart community services can be developed and provided based on collaboration of IoT devices. Sensors in numerous homes make synergetic effects for smart community services through collaboration as follows.

Energy information sharing. Homes use various energy resources such as electricity, water, and natural gas.. If home users can get the energy usages of neighboring homes, they know their relative position in energy consumption and are motivated to reduce their energy consumption.

Life style sharing. Temperature and illumination can be examples of life style in individual homes. If residents can compare their temperature and illumination with those of

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others, they are motivated to change their temperature and illumination.

Pervasive healthcare. Elder people need more efficient community healthcare. When homes are connected through H2H communication, IoT devices deployed around human body can provide emergency situation notification to nearby healthcare givers in the community.

Social networking. In a community, there are lots of people who share the same hobby, interest, leisure, and religion. People in the community may want to make their own community-specific social networking. The social networking may be a little bit private for the community.

Security and safety. Public safety is one of the most important and necessary factors in a community because safe and secure life is a general requirement of life satisfaction. Collaboration between homes helps residents get more secure and safe life. For example, when a fire occurs, the fire occurrence is reported to the nearby fire station and neighboring homes for residents to take immediate actions.

B. Types of Local Collaboration

Local collaboration based on H2H communication can be classified into several types, depending on directions of data flow between homes. Several types are as follows.

All-to-all. In energy information sharing and life style sharing services, all homes are required to share the monitored data of IoT devices in individual homes to get the maximum, average, and minimum of the whole community. Each home should transfer its monitored data to all other homes; it should receive the monitored data from them.

One-to-all. In some cases, monitored data should be transferred from one home to all other homes. Safety and security events belong to this type. Generally, a fire occurs in one home and propagates toward neighboring homes. The fire alarming should be reported to the whole community for all other homes' safety.

One-to-many. This type of collaboration is a case where one home transfers data to a special interest group (SIG) that shares the same interest. The SIG wants to share a specific information through social networking in the community.

One-to-one. Pervasive healthcare may belong to this type of collaboration because one elder person is connected to one healthcare giver such as a nurse in the community. The body status of the elder person is transferred to the healthcare giver.

III. Home-to-Home Communication Architectures for Local Collaboration

A. Home Clustering for Communication Efficiency

A community consists of numerous smart homes equipped with a HG. The larger the size of the community is, the more traffic occurs between HGs in the community. If every HG generates traffics in the community, great traffic congestion and collision will occur and degrade wireless communication performance. This degradation badly affects H2H communication. Clustering is a scheme to overcome this degradation. A group of smart homes are organized into a cluster where the cluster head (CH) plays a role of a relay for transmitting the monitored data of the member node (MN). The CH aggregates data and forwards them to other CHs.

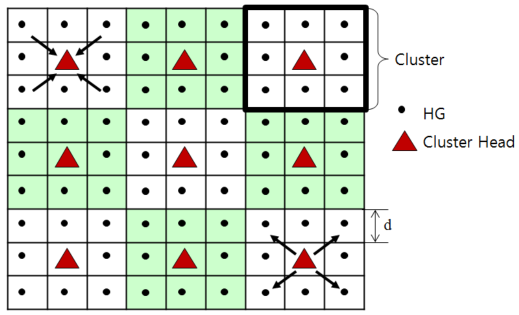

Fig. 1. Clustering of homes in a community.

Fig. 1 shows an example of home clustering in a community. Radio range needs to be greater than or equal to d√5 to guarantee the connection between neighboring HGs as in [9]. d is the width and height of equal sized homes. The dark dot stands for HG; the triangle stands for CH. Several HGs are clustered into one group; one of the HGs becomes a CH which is usually located at the center of the cluster. When CHs communicate with one another MNs located between two CHs can relay data. Clustering has another advantage: when traffics propagate over established paths between CHs, radio interference can decrease because CHs are physically apart and only several MNs operate on the paths between CHs.

B. Centralized H2H Communication

In a centralized H2H communication architecture, one selected CH among all CHs plays a role of a base station. Like a WSN network, the base station aggregates the IoT data from other CHs and sends data to them. All data are transmitted and received via the base station. Fig. 2 shows a centralized H2H communication architecture and data flow. For simplification, the upper far left CH becomes the base station. In this architecture, communication occurs between the base station and other CHs. There are two types of traffic streams: upstream and downstream. In upstream, each MN in a cluster sends the monitored data to its CH. The CH merges the data and sends the reduced data to its upper CH. In the same cluster columns, upstream traffics flow from bottom to top. In the top

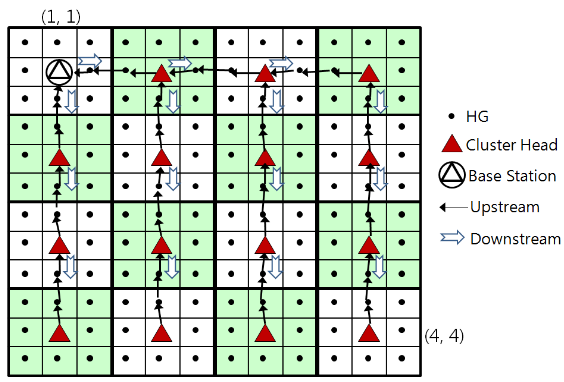

Fig. 2. Centralized H2H communication and data flow.

row clusters, upstream traffics flow from right to left. All traffics are aggregated and processed at the base station. In downstream, the base station sends the processed data to all CHs or a specific CH in the opposite direction to the upstream.

In all-to-all type of local collaboration, all homes are supposed to share the information of common interest. Energy information sharing and life style sharing belong to all-to-all type. For example, in energy information sharing, each HG aggregates energy information from its IoT devices. HGs in a cluster send the data to their CH. The CH merges and produces the maximum, average, minimum, and the number of HGs in the cluster. Each CH sends this processed data towards the base station and transfers the received data from the bottom (right) to the top (left) CH. The base station aggregates the data from all CHs and processes them into new maximum, average, minimum, and the number of HGs in the community.

C. Distributed H2H Communication

In a distributed H2H communication architecture, there is no base station which aggregates and disseminates data. If a source HG has data to share in the community, it sends the data to its CH. The CH sends the data in three directions when it belongs to the corner clusters; it sends the data in four directions when it belongs to inside clusters; and, it sends the data in two direction when it belongs to the edge clusters. When a CH receives the data from the left (right) CH in the same row clusters, it sends the data to the right (left) CH. Only in the same row clusters, there are horizontal traffics. In the other row clusters, only vertical traffics are generated. Fig. 3 shows the distributed H2H communication architecture. The community is composed of 4×4 clusters that consist of nine HGs. When a HG at the location (3,1) sends data to its CH, the corresponding CH (3,1) sends the data in three directions: up, down, and right. The data is transferred to the upper and lower CHs in the same column clusters. In the same row clusters, the data propagates towards CH (3,4).

In case of one-to-all type of local collaboration, a source HG sends the data to its CH. The CH transfers the data to neighboring CHs. Each CH broadcasts the data to its MNs and relays them to next CHs over the paths between CHs. The CHs instantly broadcast the data to its MNs right after they receive the data from other CHs. As a result, the alarming data propagate from the source HG to nearby neighboring HGs and

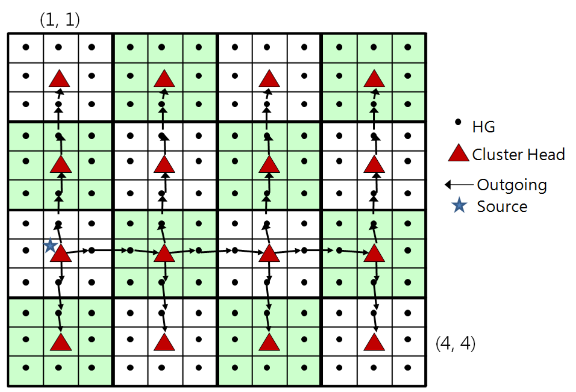

Fig. 3. Distributed H2H communication and data flow.

then to the farthest ones. In one-to-all type of local collaboration, the distributed architecture is more efficient.

IV. EVALUATION

To evaluate two types of H2H communication architectures, traffic volume and communication reliability are presented in a normal network and a clustered network, respectively. To make evaluations easy and simple, it is assumed that the community is composed of N rows and N columns and that one cluster consists of $K \times K$ HGs (K = 1, 3, 5, 7, …). Total number of HGs is $N \times N$.; total clusters are $(N/K)^2$.

A. Traffic Volume

Traffic volumes in the centralized and distributed H2H communications in all-to-all type are compared. In a centralized H2H communication, as shown in Fig. 2, the farther a CH is from the base station, the more traffics are generated. In the first row, the base station generates no upstream traffic. The second CH generates one upstream traffic count. The far right CH generates N/K-1 upstream traffic counts. Upstream traffic counts increase in proportion to the column number in the same row. Likewise, upstream traffic counts increases as the row number increases. Total CH upstream traffic counts on the cluster layer are calculated as in (1). In downstream, the base station broadcasts the data. The traffic counts are the number of transmission relays in the CHs. In Fig. 2, bottom CHs generate no traffic. The downstream CH traffic counts are $(N/K)^2$-1. Because hop counts between two CHs are K, total traffic counts is calculated as $K[(N/K)^3-1]$ by multiplying the sum of upstream and downstream by K. Traffic counts inside a cluster in both upstream and downstream are easily calculated as $(K-1)K(K+1)$ in unicast. Total traffic counts in a centralized H2H communication architecture are calculated as in (2).

$$\sum_{n=1}^{\frac{N}{K}}\sum_{m=1}^{\frac{N}{K}}\{(n-1)+(m-1)\}=\left(\frac{N}{K}\right)^2\left(\frac{N}{K}-1\right) \tag{1}$$

$$K\left\{\left(\frac{N}{K}\right)^3-1\right\}+(K-1)K(K+1) \tag{2}$$

In a distributed H2H communication, when a certain CH generates a traffic. N/K-1 traffics occur in a corresponding row; in each column, N/K-1 traffics occur. There are N/K columns. Total traffic counts on the cluster layer are $(N/K)^2$-1. Because hop counts between two CHs are K, total traffic counts is calculated as $K[(N/K)^2-1]$ by multiplying traffics per CH by K. All CHs equally generate traffics; therefore, the number of CHs needs to be multiplied. Traffics inside a cluster are $(K-1)K(K+1)$ as in the centralized architecture. Therefore, total traffic counts are calculated as in (3).

$$K\left(\frac{N}{K}\right)^2\left\{\left(\frac{N}{K}\right)^2-1\right\}+(K-1)K(K+1) \tag{3}$$

Fig. 4 shows the traffic volumes in all-to-all type of local collaboration for two cases: no cluster and a cluster size of 3×3. Traffics in the distributed architecture increases more steeply than that in the centralized one. Clustering greatly

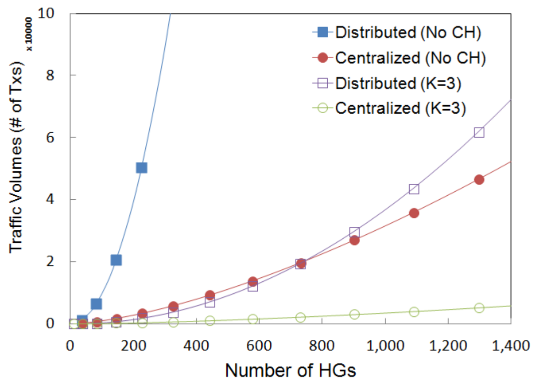

Fig. 4. Comparisons of traffic volumes versus the number of HGs in all-to-all type of local collaboration.

reduces traffic volumes in both architecture. Therefore, in all-to-all type of local collaboration, a centralized architecture is superior to a distributed one.

B. *Communication Reliability*

In general, wireless communication reliability decreases in proportion to the number of hops. A path length is defined as the number of hops between two HGs. In a safety and security services, it is desirable that a path length in a worst case be considered. For example, a fire in cluster (4,4) is reported to its neighboring cluster (4,3) in Fig. 2.

In a centralized architecture, if a fire occurs at the farthest cluster from the base station, the event CH notifies the base station of a fire. Then, the base station notifies all CHs of a fire alarming. The upstream hops are 2(*N*/*K*-1). The downstream hops to the neighboring CH are 2(*N*/*K*-1)-1. Because hops between two CHs are *K*, the sum needs to be multiplied by *K*. Both upstream and downstream maximum hops inside a cluster are *K*-1. As a result, total path lengths are calculated as in (4).

$$K\left\{4\left(\frac{N}{K}-1\right)-1\right\}+2(K-1) \quad (4)$$

In a distributed architecture, the event CH (3,1) can notifies the nearest neighboring CH (3,2) of a fire alarming

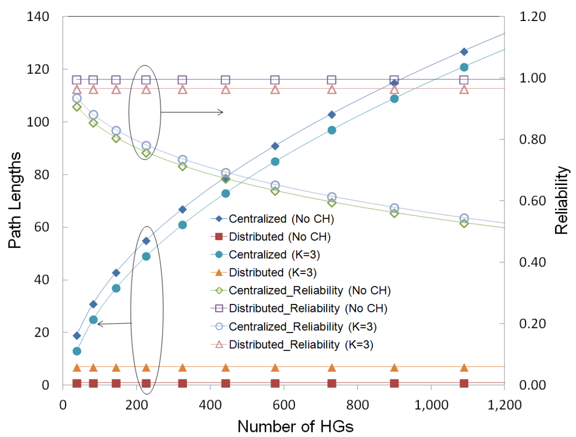

Fig. 5. Comparisons of path lengths and reliability versus the number of HGs in one-to-all type of local collaboration.

with *K* hops in Fig. 3. Both upstream and downstream maximum hops inside a cluster are *K*-1. As a result, total hops are 3*K*-2. The path length is always constant regardless of the community size because CHs in a distributed architecture always notify the nearest CH of a fire alarming.

Fig. 5 shows the path lengths and the reliabilities when one hop reliability is 99.5% for two cases: no cluster and a cluster size of 3×3. The path length almost linearly increases in a centralized architecture while the path length in a distributed architecture is always constant. As a result, the reliability in a centralized architecture exponentially decreases while that in a distributed one is constant. In one-to-all type of local collaboration for safety and security services, a distributed architecture is superior to a centralized architecture.

V. CONCLUSIONS

In this paper, two H2H communication architectures are presented for local collaboration. They are evaluated by traffic volume and communication reliability. Clustering technology is adopted to reduce traffic volumes. First, regarding traffic volume, the distributed architecture in all-to-all type of local collaboration generates more steeply increasing traffic volumes than the centralized architecture. The centralized architecture is superior in all-to-all type. Second, regarding communication reliability, the distributed architecture is superior to the centralized one because the necessity of a base station in the centralized one always requires more hops than the distributed one. If H2H communication architectures are dynamically adopted depending on smart community services, H2H communication will provide more efficient communication and reliable smart community services.

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